DAMAGE DUE TO ELECTRIC SPARK DISCHARGE MACHINING OF ZINC*

by A. P. L. Turner, K. H. Adams**, and T. Vreeland, Jr.
W. M. Keck Laboratory of Engineering Materials
California Institute of Technology, Pasadena

Research on the properties of dislocations in metal single crystals has created a great need for methods of shaping suitable test specimens from larger single crystals. Acid cutting methods involving sawing and turning operations have been used with success. However acid machining has several disadvantages which include slow machining rates and the difficulty of producing surfaces which are sufficiently flat for test purposes. Electrical discharge machining does not have these disadvantages, but little is known about the depth of the plastically deformed layer below a surface machined by this method. Samuels[1] has found that in polycrystalline 70-30 brass the depth of the plastically deformed zone is limited to 45 microns below a surface planed with low energy sparks. A study of the effects of electric spark discharges on the (111) plane of bismuth and antimony and the (0001) plane of zinc by Palatnik[2] indicates that the depth of the plastically deformed zone is approximately 125 microns. Although Palatnik observed that the geometry of the plastically deformed zone was influenced by crystallographic orientation, little work has been reported on situations where plastic anisotropy is an important parameter.

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** Present address: Engineering Department, Arizona State University, Tempe, Arizona.

Work done on 99.999% pure zinc single crystals in this laboratory has indicated that in some cases conditions of plastic anisotropy and electric spark machining at relatively high temperatures can interact to produce much more extensive damage. Deformation extending six millimeters below a machined surface has been observed after the removal of approximately one millimeter of material by planing.

The work described was done on a Servomet Electric Spark Discharge Machine using the lowest spark energy range of the machine. All machining operations were done in oil heated to approximately 100° C because it had previously been found that machining at temperatures below 90° C initiated cleavage fractures on the basal (0001) planes. Planing operations were carried out on specimens of two different orientations, one of which exhibited extensive deformation as the result of the machining and one of which did not. The specimens which exhibited deformation were cubes which were oriented with one side parallel to the prism $(10\bar{1}0)$ planes and the sides perpendicular to this at 45° to the basal planes. The specimens which were not deformed by planing were oriented with one side parallel to prism planes and the perpendicular faces at 80° and 10° to the basal planes. Fig. 1 shows the orientations of the two types of specimens.

Planing of surfaces which are at 45° to the basal plane produces severe deformation by kinking and by slip. Deformation by kinking is found near one of the two free edges of the specimen (as viewed from the prism surface) and deformation by slip is found near the other edge. A photomicrograph of a replica of an etched prism surface which reveals the deformation resulting from the removal of 0.5 mm of material by spark planing is shown in Fig. 2a. The etch of Brandt et. al.[3] was used. No severe deformation results from the planing of surfaces oriented 10° or 80° from the basal plane. Experiments have shown that the nature of the deformation is independent of the direction of motion of the planing wheel across the specimen. It is therefore evident that the deformation results from loads applied normal to the planed surface and not from viscous shear forces. Annealing the crystal resulted in the formation of the substructure shown in Fig. 2b. Note the bulge on the left edge resulting from the kinking, and the substructure aligned generally along the [$\bar{1}2\bar{1}0$] near the top right hand corner.

A mechanism is proposed below which describes the formation of the observed damage and is consistent with the deduced character of the loading. During the planing operation the specimen is subjected to repeated impulsive point pressure forces resulting from the collapse of cavitation bubbles. Cavitation is known to occur because the electrical discharge causes a rapid vaporization of the oil in the immediate vicinity of the spark. Dislocations are generated at the surface and in the vicinity of the spark. A concentrated load on a free surface produces resolved shear stresses on the basal glide plane which are the same sign everywhere in the highly stressed region as shown schematically in Fig. 3a. This stress configuration will drive dislocations of one sign into the crystal while those of the opposite sign are driven to the surface as shown in Fig. 3b. Near one edge of the crystal the resulting concentration of edge oriented dislocations of a single sign can polygonize to form a series of kinks which extend from the planed surface to the side surface as illustrated in Fig. 3c. At the other edge of the crystal the dislocations will be driven out of the lateral surface of the crystal. The average pressure on the planed surface is sufficient to cause the kinks to move from the edge into the crystal by glide and to form the slip bands observed near the other edge. The 45° orientation is the most favorable for the formation of kink bands and slip. For this orientation the strain energy associated with the kinks is a minimum while the resolved shear stress on the dislocations is maximum. The resolved shear stress is insufficient to cause severe deformation during the planing of surfaces oriented 10° or 80° from a basal (0001) plane.

The deformation can be prevented by constraining the lateral sides of the crystal so that they remain flat. This can be done most readily without damaging the specimen by gluing blocks of zinc (hardened by impurity additions) to the lateral sides of the crystal. Duco cement is used, and the blocks have the same crystallographic orientation as the specimen. The entire assembly is then planed. The constraints provided by the blocks on the sides keep kinks and slip from being driven into the specimen crystal. The use of the same material for the side blocks assures that the specimen will not be damaged by mismatch of thermal expansion or elastic properties between the specimen and the supporting blocks.

REFERENCES

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[2] L. S. Palatnik, A. A. Levchenko, and V. M. Kosevich, Soviet Phys.-Cryst. 6,(1961) 472.

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CAPTIONS

Fig. 1. Orientation of cubic specimens with surfaces finished by spark planing.

(a) Orientation of specimens which exhibit extensive deformation after spark planing.

(b) Orientation of specimens which do not exhibit extensive deformation after spark planing.

Fig. 2. Photomicrographs showing damage resulting from the revomal of 0.5 mm by spark planing at 100°C.

(a) Replica of an etched $(10\bar{1}0)$ surface after planing (reversed in printing).

(b) Re-etched surface after crystal was annealed for 24 hr. at 370°C.

Fig. 3. Schematic illustration of spark machining damage.

(a) Concentrated load and resolved shear stress.

(b) Edge dislocations driven into crystal by the resolved shear stress.

(c) Kink bands and bulge produced on left edge of specimen.

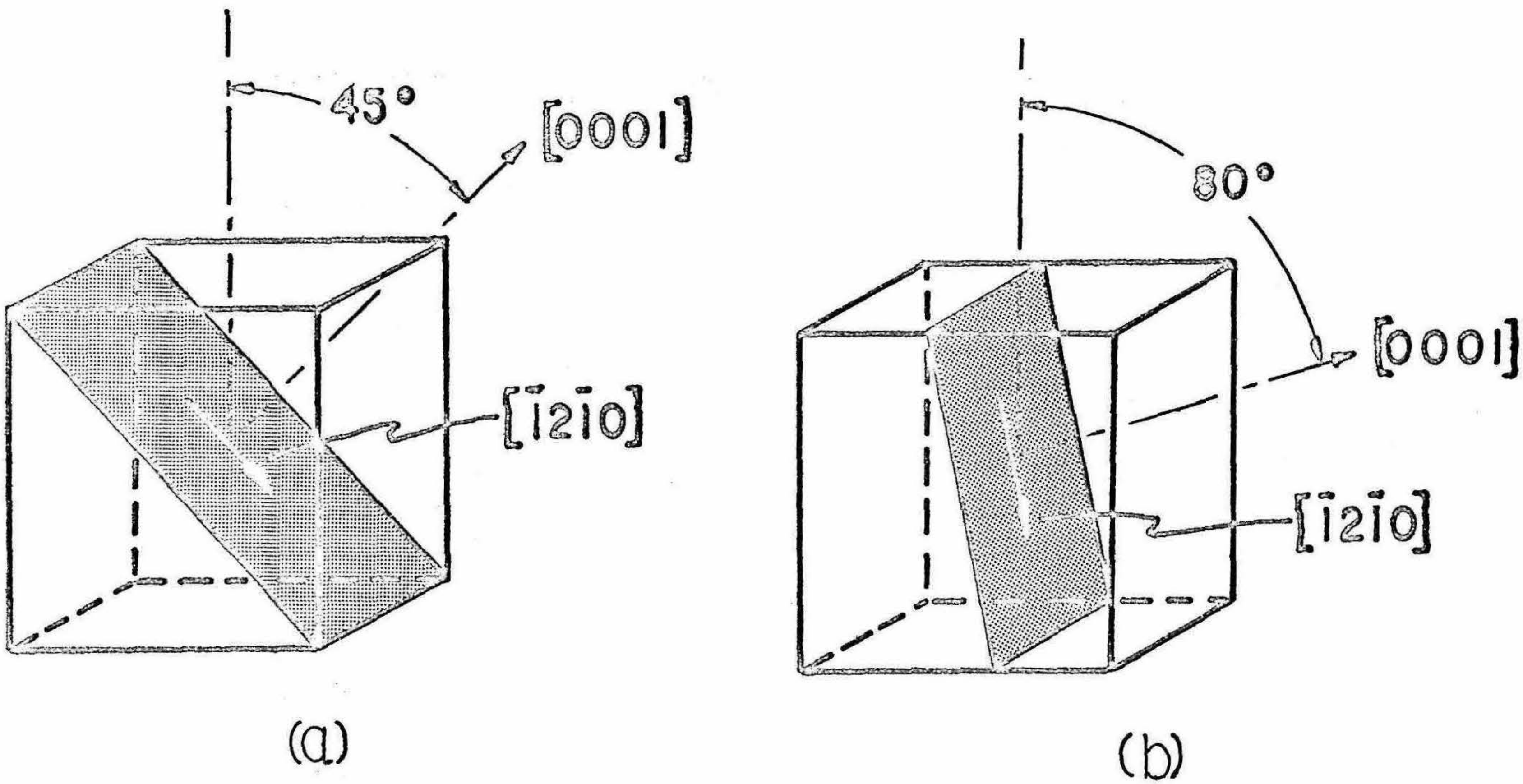
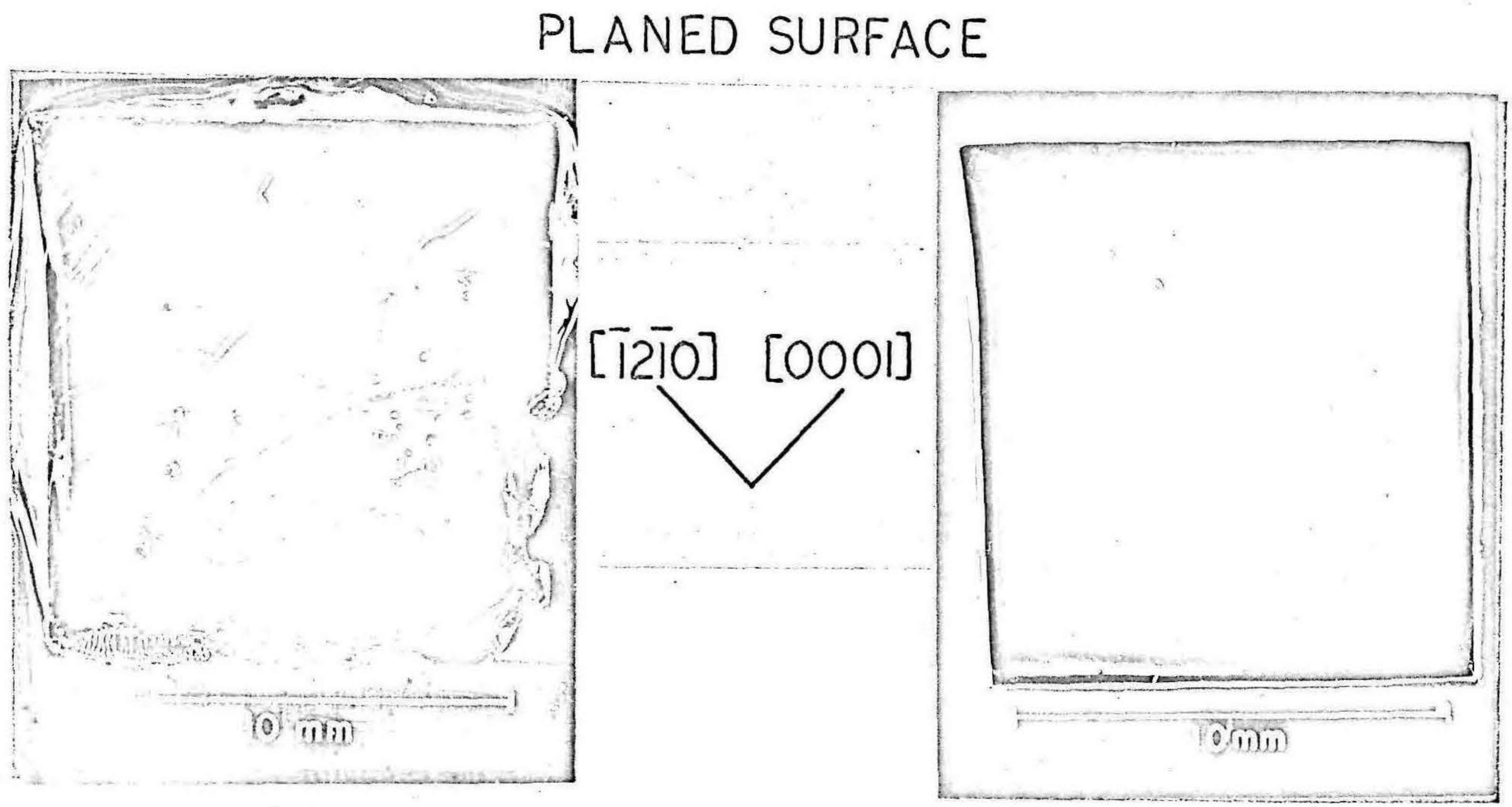


Fig. 1



(a)
(b)

Fig 2

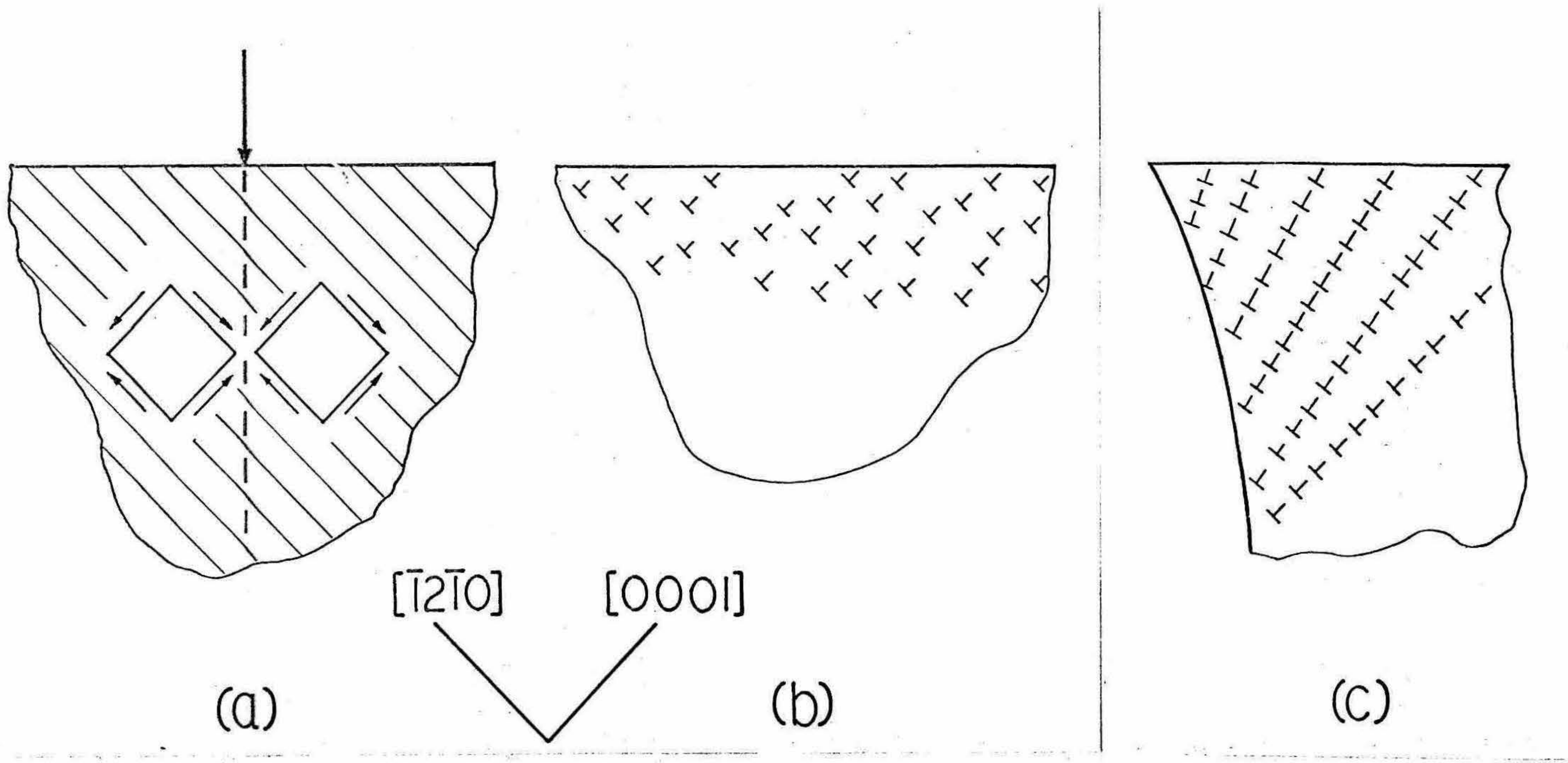


Fig. 3